# Spectral Wave Decay Due to Bottom Friction
# on the Inner Shelf

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## LONG TERM GOALS

Long term goals are to observe and model wave and current boundary layer processes to determine wave dissipation and wave-bed interactions in coastal and nearshore regions using novel instrumentation techniques.

## SCIENTIFIC OBJECTIVES

The primary scientific objective of this project is to measure the bottom dissipation of surface gravity waves as they shoal across the continental shelf, as a component of the Shoaling Waves Experiment, SHOWEX. Detailed observations of the bottom boundary layer, resolving the thin oscillatory wave boundary layer, are being made at two sites with differing wave forcing, mean currents and sediment bed types, to develop a spectral wave dissipation model for the continental shelf. At each site, continuous maps of the small-scale morphology have been made in an area surrounding the detailed bottom boundary layer measurements to study changes in the bed in response to wave forcing, and to relate the effects of these morphology changes on the turbulence in the BBL.  The spectral dissipation model will include the potentially strong influence of a wave-forced mobile bed, and parameterizations for low frequency currents including strong baroclinic tidal and wind-driven currents.

## APPROACH

During 1999, two long term inner shelf observation sites were established to measure wave and current forcing and detailed measurements of BBL - bed responses. The Monterey Inner Shelf Observatory (MISO, Stanton 1999) has a shore-cabled instrument frame at 12m depth in the southern end of Monterey Bay at a site with .15mm mean diameter sandy bed and moderate, primarily narrow band, long period swell forcing conditions. A second site was established in 11m of water offshore from the Duck pier between 28 September and 10 December 1999 during the main SHOWEX observation program. The Duck site has significantly finer sediment and forcing is generally shorter period, with

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frequent energetic wave forcing, and strong, low frequency, longshore currents in comparison with the Monterey site. A year-long wave forcing and bed response at the Monterey Bay site is continuing, providing a unique data set to test ripple formation models over a wide range of seasonal wave forcing conditions.

At each field site, dissipation rates in the bottom boundary layer have been estimated from O(1cm) resolution, three component velocity profiles measured by Bistatic Coherent Doppler Velocimeter (BCDV) instruments (Stanton 1996, 2000). These instruments measure vertical profiles of velocity and sediment concentration over a 60 cm range above the bed at a 20Hz rate. These small-scale measurements of the bottom boundary layer are extended through the water column with high speed Broad Band Acoustic Doppler Profilers. Wave dissipation rates in the mean current and wave-forced bottom boundary layer are being estimated by decomposing mean, wave, and turbulent components of the three component velocity vector profiles to estimate the wave work term dissipating wave energy in the BBL. The co-located measurements of the velocity vector profiles and sediment concentration allow the sediment buoyancy terms in the TKE balance in the bottom boundary to be estimated when sediment suspension is occurring. As the local sediment morphology can greatly influence the characteristics of the bottom boundary layer (eg. Faria *et al* 1998), a two axis scanning sonar altimeter was developed to quantitatively measure finescale morphology over a 4 by 2 m area centered on the BCDV profile measurements with 4cm horizontal and 0.25 cm vertical resolutions. These local morphology maps were extended at the Duck site by qualitative 2D side-scan morphology images out to a 10m radius around the instrument frame to identify larger scale morphological features. Three cross-shelf side-scan swaths of the bed were measured in collaboration with Tom Herber's and Fred Dobsons's group to estimate mobile bed changes to strong forcing events.

The DUNE2D boundary layer model for small-scale morphology (Andersen, 1999) is being used by a graduate student to model bedform development measured at the Duck site. The model consists of inter-linked modules for flow, sediment transport and morphology. The flow module is based on solving the Navier-Stokes equations in the vertical plane with k-epsilon turbulence closure. This model has been extended to accept generalized velocity time series forcing at the lateral boundaries and a general (but periodic) bottom boundary to be able to compare with field data, and is being used to assess the level of model sophistication needed to predict the observed bed responses. The objectives in our modeling efforts are to test and improve on existing ripple formation models based on spectral wave forcing and prescribed mean currents, and to compare predicted wave stress and wave work rates with the SHOWEX observation timeseries. The BBL dissipation formulations will be tested against *in situ* cross shelf directional wave buoy observations being made by Herbers and O'Rielly at the SHOWEX site, and incorporated into a shelf wave model being developed by Phd student Fabrice Arduian and Tom Herbers (Arduin et al, 2000).

**WORK COMPLETED**

Analysis of data from prototype versions of the BCDV and scanning altimeter used during SandyDuck and the SHOWEX observations have allowed techniques to be developed for estimating Reynolds stresses and dissipation rate profiles across the thin oscillatory boundary layer above a sloping and

rippled bed. Part of this work has been accomplished with theoretical contributions from NICOP collaborators Paolo Blondeux and Geovana Vittori. (Blondeaux et al 1999 and 2000).

Results from Direct Numerical Simulations of a randomly forced oscillatory bottom boundary layer being run by SHOWEX collaborator Donn Slinn are being used to explore how the finite sample volume, vertical profiles of velocity made by the BCDV can be optimally used to measure the wave dissipation rates. High resolution model output from a flat bottom run have been "sampled" using the acoustic response of the BCDV to define what part of the stress and strain and shear field is resolved by the instrument, and importantly, what turbulence terms contributing to dissipation are not resolved. These analyses are being repeated with more recent model runs with bedforms and bottom roughness more representative of the observed field conditions. These detailed simulations suggest that the limited resolution oscillatory boundary layer measurements made with the BCDV adequately resolve the dominant wave-induced shear production terms across the oscillatory boundary layer for bed morphologies observed both at Duck and Monterey Bay.

Processing of the X/Y altimeter bed-form timeseries has been completed, and a preliminary analysis of the bedform response has been submitted (Stanton and Thornton 2000). A MS thesis was completed, analyzing a 1mm resolution, 60cm cross-shore transect timeseries of bed slope using a video camera and structured light system. This work showed the changes of slope and bedform orientation in relict bedforms under low forcing following strong forcing events. A more comprehensive bedform modeling effort considering the full timeseries ( 2 months from Duck and 12 months from Monterey Bay sites) is in progress.

**RESULTS**

Analysis of the 0.6cm resolution vertical profiles of three component velocity measured by the BCDV have allowed the near-bed vertical Reynold's stress profiles to be estimated while minimizing the contributions of the strong wave-induced oscillatory flow to the cross-shore <v'w'> correlations. Under moderate to strong wave conditions, the stress profile is resolved across the 4 to 10cm thick oscillatory boundary layer allowing a $\tau_{0w}$ wave bed stress to be estimated. The resulting wave work rate compares favorably to the integrated wave shear production term estimated across the oscillatory boundary layer. A paper describing these wave work and stress estimates through two storm events is being written.

A consistent feature of our bed morphology measurements made both acoustically and optically is the persistence of significant relic ripple fields between strong wave forcing events.

The importance of the relic bedforms is illustrated by a two day timeseries of forcing and bed response at the SHOWEX instrument frame at Duck NC. Figure 1 is a wave height spectral timeseries showing 0.4 m significant wave heights up to yearday 315.7, then 4 second period local seas rapidly developing into 8 s, 2.8 m significant height waves by day 316.2. The response of the 12m depth bed to this event is summarized in the bed map timeseries in Figure 2. Each mesh surface shows a 1.5 m cross-shore by 1m long-shore area of the bed under the 1m high "goal post" instrument frame. Only small scale changes (not seen in these small plots) occur prior to a sudden transition at the end of day 315, when

the combined orbital motion and mean current exceeds a critical shields parameter and the bed rapidly flattens out, then reforms into a 1.2m wavelength, large scale, more three dimensional ripple as the wave forcing decreases during day 316. The long persistence of these relic bedforms has significant implications on modeling BBL wave dissipation rates at larger scales, as these bedforms provide the dominant dissipation mechanisms for moderate swell events until the next strong forcing event "rearranges" the bed again.
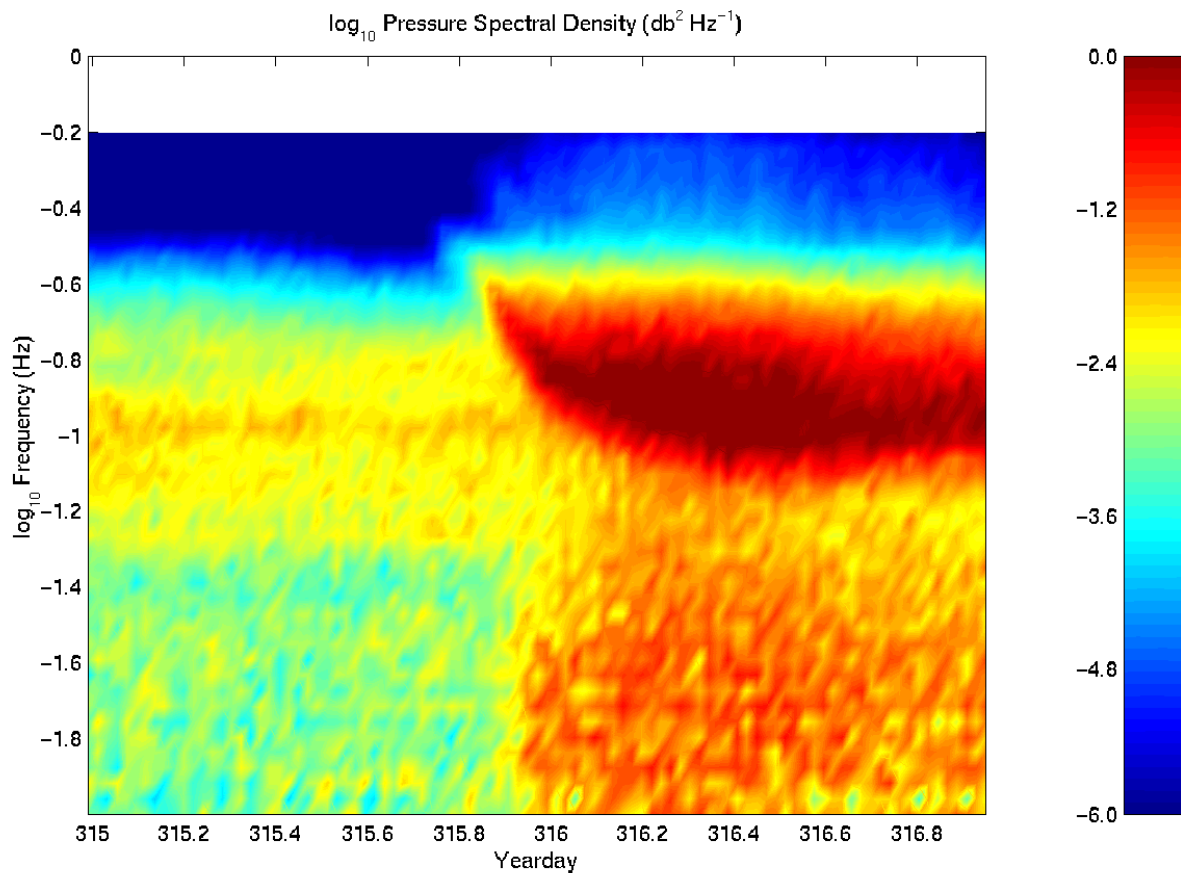


*Figure 1. A two day timeseries of wave height spectral density at the SHOWEX bottom boundary layer measurment array at Duck NC. The x axis is yearday in 1999. A wind event rapidly developed at the end of yearday 315 into a 2.8m significant wave height swell.*
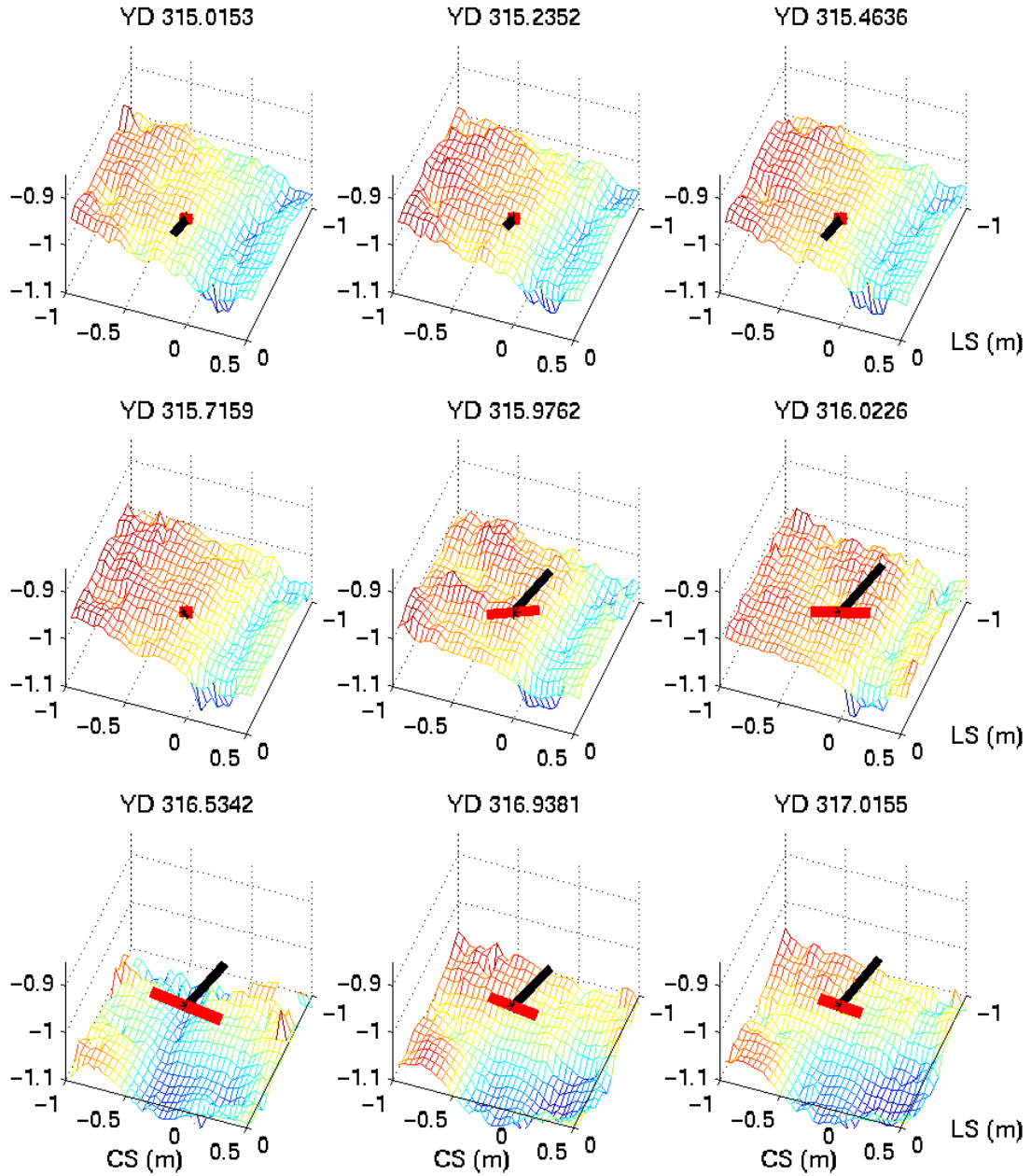
*Figure 2. This sequence of mesh surfaces shows the temporal evolution of the sandy bed below the 12m depth instrument frame during the same two day period as Figure 1. The x-axis is aligned with the cross-shore . The z axis shows the distance from the scanned altimeter to the bed. The red bar shows the rms relative amplitude of the near-bed velocity (dominantly cross-shore) while the black bar shows the 30 minute mean current on the same relative scale.*

## IMPACT / APPLICATIONS

Observations of cross-shelf wave shoaling and energy loss under low wind conditions across the continental shelf (for example Herbers et al, 2000) suggest that bottom dissipation is a zero th order term in the cross-shelf wave evolution. Modelling of bottom dissipation in coastal regions will directly improve shelf wave models, which have wide ranging navy and civilian applications.

## RELATED PROJECTS

This research has benefited from and contributed to the ONR-sponsored SandyDuck program in the development and deployment of the scanning X/Y altimeter and the prototype BCDV, which address overlapping issues in both programs.

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